A Roadmap for NASA's Radiation Effects Research in Emerging Microelectronics and Photonics

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Abstract – The Electronics Radiation Characterization (ERC) project of the NASA Electronic Parts and Packaging (NEPP) Program is responsible for the radiation effects research on microelectronics and photonics for NASA. In this presentation, we present our roadmap for providing aid to NASA flight projects, technology developers, and the aerospace community.

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1. INTRODUCTION

Among the most unique aspects of developing systems for space is the performance of electronic systems in the natural space radiation environment [1]. Long and short term radiation effects such as total ionizing dose (TID), displacement damage (DD), and single event effects (SEE) provide aerospace designers' a myriad of challenges for system design. The radiation hazard that a designer faces is not generic: each mission orbit, timeframe, duration, and spacecraft design (mechanical and electrical) provides differing requirements and challenges to deal with. This hazard varies:

- from missions with severe requirements that fly in the heart of the Van Allen belts (such as a medium earth orbit or MEO)
- to avionics systems in the upper atmosphere that are protected from many energetic particle concerns, but still must deal with secondary particles such as neutrons.

The thought of an error occurring in the electronics of a manned aircraft or spacecraft is unsettling at best.

With this in mind, NASA's ERC Project is responsible for supporting NASA's current and future needs in providing reliable electronic systems in the natural space and terrestrial radiation environments. These systems range from deep space probes with long lifetimes to earth and space science missions to the Space Shuttle short duration missions to avionics in aircraft. In this regard, the ERC project's roles are to:

- provide radiation evaluations and assessments of new and emerging microelectronic and photonic technologies to enhance infusion into NASA missions,
- develop guidelines for technology usage in radiation environments, and
- investigate radiation hardness assurance (RHA) issues in order to increase system reliability and reduce cost and schedule.

We work collaboratively with technology developers and users to understand radiation needs, issues, sensitivities, and hardening solutions. The underlying goal of the ERC Project is to aid NASA's and the aerospace industry's designers to meet *their challenges* in areas such as performance, reliability, and resources. If the ERC Project is sufficiently funded and we do our job correctly, much of what is accomplished by this project is transparent to the mission management structure: we are able to discover and solve technology challenges *before* NASA missions choose to implement the technology in flight. They, the missions, simply qualify the technology that has been assessed including any hardening schemes that are required and integrate this technology into their system.

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2. THE BASICS OF RADIATION EFFECTS FOR MICROELECTRONICS

Ionizing radiation effects in space vehicle electronics can be separated into two areas: TID and SEE [2]. The two effects are distinct, as are the requirements and mitigation techniques. In addition, the non-ionizing radiation effects such as displacement damage must be considered [3].

TID is due to long-term degradation of electronics due to the cumulative energy deposited in a material. Effects include parametric failures, or variations in device parameters such as leakage current, threshold voltage, etc., and functional failures. Significant sources of TID exposure in the space environment include trapped electrons, trapped protons, and solar protons.

Displacement damage often has similar long-term degradation characteristics like TID, but is a separate physical mechanism. Devices that are tolerant to TID are NOT necessarily tolerant to displacement damage. Prime sources of displacement damage exposure include trapped protons, solar protons, Radioisotopic Thermoelectric Generator (RTG) neutrons, and to a lesser extent, trapped electrons.

SEEs occur when a single ion strikes the material, depositing sufficient energy in the device to cause an SEE. The many types of SEE may be divided into two main categories: soft errors and hard errors. In general, a soft error occurs when a transient pulse or bit-flip in the device causes an error detectable at the device output. Therefore, soft errors are entirely device specific, and are best categorized by their impact on the device. Single Event Upset (SEU) is generally a transient pulse or bit-flip. In combinatorial logic or an analog-to-digital converter, a transient or spike on the device output would be a potential SEU; in a memory cell or latch, a bit-flip would be an SEU. SEUs occurring in the device's control circuitry may also cause other effects. In general, SEUs are corrected by resetting the device, adding error detection and correction (EDAC) capabilities, or rewriting the data. During Single Event Functional Interrupt (SEFI), the device halts normal operations, often requiring a power reset to recover. SEFI most likely occurs when an SEU in the device's control circuitry places the device under test (DUT) into a test mode, or a halt or undefined state. Again, this depends on the device itself.

Hard errors may be - but are not necessarily - physically destructive to the device, and cause permanent functional effects. Single Hard Error (SHE) causes a permanent change to the operation of the device. A common example would be a stuck bit in a memory device. Like SEUs, this is also device dependent. Single Event Latchup (SEL) is a potentially destructive condition involving parasitic circuit elements. During a traditional or destructive SEL, the device current exceeds the maximum specified for the device. Unless power is removed, the device will eventually be destroyed. A micro-latch is a type of SEL where the device current is elevated, but below the device's specified maximum. Again, a power reset is required to recover normal device operation. Single Event Burnout (SEB) is a highly localized *destructive* burnout of the drain-source in power MOSFETs (metal oxide semiconductor field effect transistors). Single Event Gate Rupture (SEGR) is the *destructive* burnout of a gate insulator in a power MOSFET.

The SEE sensitivity of a device is discussed in terms of Linear Energy Transfer (LET) and Cross Section (σ). LET is a measure of the energy deposited per unit length as an ionizing particle travels through a material. The common unit is MeV*cm^2/mg of material (Si for Metal Oxide Semiconductor devices). LET threshold (LET_{th}) is the minimum LET to cause an effect, at a given particle fluence of 1E6 or 1E7 ions/cm^2. The σ reflects the device area which is sensitive to ionizing radiation. For a specific LET, cross section is calculated: σ = #errors/particle fluence. The units for cross section are cm^2 per device or per bit. Sensitive volume refers to the device volume affected by SEE-inducing radiation. The sensitive volume is, in general, much smaller than the actual device volume.

3. RADIATION TOLERANCE AND REQUIREMENTS

NASA has a unique mix of missions ranging from short-duration avionics and balloon experiments to long-life deep space, crewed, and science based spacecraft [4]. In addition, the advent of the "faster, better, cheaper" (FBC) philosophy is driving missions to:

- reduce time to launch (faster),
- increase system performance (better) and
- reduce system size and power consumption with reduced resources such as manpower (cheaper).

This has direct implications in the choice of microelectronics and photonics by system designers. In particular, the designers select components to meet such needs as:

- higher performance,
- increased off-the-shelf availability (decreased lead time for procurement),
- reduced power consumption,
- increased device and system integration, and
- novel packaging/interconnect schemes.

As you might note by its missing from the above list, radiation tolerance of these components is often a secondary consideration. This is unfortunate considering the impact radiation can have on mission performance (or failure).

High	Moderate	Low
• > 100 krads (Si)	• 10-100 krads (Si)	• < 10 krads (Si)
• May have	• May have	• May have
– long mission duration	– medium mission duration	– short mission duration
– intense single event environment	– intense single event environment	– moderate single event environment
– intense displacement damage environment	– moderate displacement damage environment	– low displacement damage environment
Examples: Europa, GTO, MEO Type of device: Rad hard (RH)	Examples: EOS, highLEO, L1, L2, ISSA Type of device needed: Rad tolerant (RT)	Examples: HST, Shuttle, XTE Type of device needed: SOTA commercial with SEE mitigation

GTO	GeoTransfer Orbit	ISSA	International Space Station Alpha
EOS	Earth Orbiting System	HST	Hubble Space Telescope
LEO	Low Earth Orbit	XTE	X-ray Timing Explorer
L1, L2	LaGrange Point Orbits	SOTA	State-of-the-Art

Figure 1 Mix of NASA Missions and Radiation Requirements

Figure 1 illustrates the typical categories for radiation tolerance of microelectronics for NASA. No formal study has been performed, however, it is expected that the majority (with some notable exceptions) of NASA missions fit into the "medium" category where typical commercial (re: non-radiation hardened) devices struggle to meet mission requirements. Unfortunately, the radiation hardened device alternatives often do not meet performance constraints such as bandwidth and power consumption and are in many cases 6-8 years behind their commercial counterparts in these performance characteristics.

This mix of missions has several implications. Whereas TID and displacement damage are still concerns, SEE tolerance appears to be the prime driver. One might speculate that true radiation hardened devices might enable NASA science missions into new mission scenarios such as deep space or MEO.

A second implication of this mission mix is the potential for use of commercial technologies for some NASA missions with low radiation requirements or by the addition of radiation mitigative schemes. Even missions with relatively low radiation requirements, such as Hubble Space Telescope (which has observed several radiation-induced anomalies) [5-7], offer challenges for performance in their radiation environment. One must remember that radiation lot acceptance tests (RLATs) of these devices should be performed in the majority of instances.

Two final notes on the wide range of NASA radiation requirements are:

- that the need for both commercial devices (example, space shuttle experiment) and radiation hardened devices (example, Europa) exist, and
- that even seemingly "safe" NASA missions such as balloon experiments and avionic systems have issues with secondary particle SEEs.

In fact, terrestrial radiation-induced soft errors have become a concern for the commercial semiconductor industry as device technologies have scaled and power supply voltages have dropped [8].

4. NASA's Microelectronics Needs – An ERC Perspective

NASA's Space Science Strategic Plan states that NASA has two general categories for enabling technologies [9]. These are:

- Technologies that provide fundamental capabilities without which certain objectives cannot be met, or that open completely new mission opportunities; and
- Technologies that reduce cost and/or risk to such a degree that they enable missions that would otherwise be economically unrealistic.

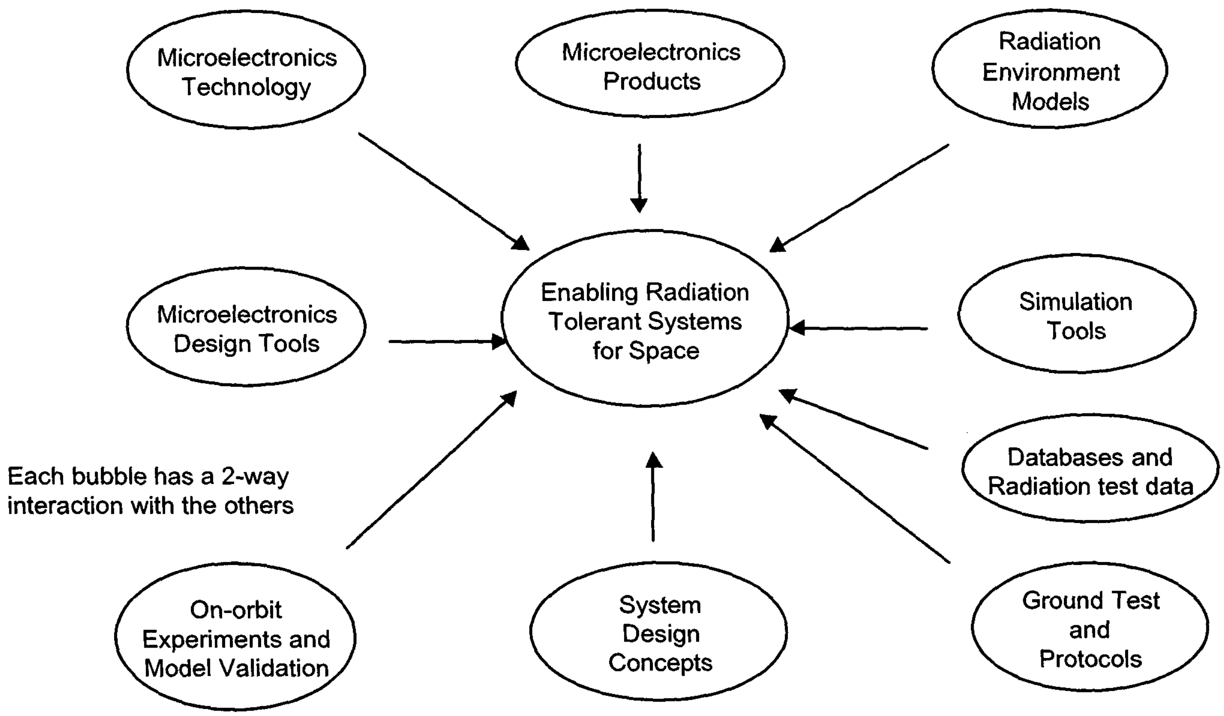


Figure 2 Radiation Tolerance Roadmap

Radiation support is critical to the use and infusion of new and emerging microelectronic and photonic technologies into NASA systems. Figure 2 illustrates the bigger picture of what it takes to provide radiation tolerant, high performance electronic and photonic systems. In this perspective, the ERC project is focused on providing critical ground radiation tests and evaluations, development of ground radiation test methods and protocols, and extension and development of radiation test databases in support of technology developments, space environment models and monitors, system design concepts, and on-orbit experiments. We are the ground radiation test arm that must interact closely with the space-based arms (on-orbit experiments and environment issues) and technology developers to ensure that we are meeting NASA's needs. Thus, the ERC co-aligns itself with NASA organizations such as the Space Environment and Effects (SEE) Program, Cross-Enterprise Technology Development Program (CETDP), and supports planning for efforts such as the Orbiting Technology Testbed Initiative (OTTI). In this regard, the SEE program might, for example, support the development of space experiments and modeling of the space radiation environment, while the ERC project supports the correlation of space flight performance with the ground test data and prediction methods.

From the more detailed microelectronics perspective, NASA's needs are seemingly all-encompassing. Table 1 is a representative list of factors affecting the future choice of microelectronic technologies for NASA missions. It may be simply stated that designers are seeking devices for increased system performance while providing enabling characteristics such as low power, volume, and cost. New and exciting emerging microelectronic technologies may well help meet many of these performance goals.

Table 1 Desirable Features for Future NASA Missions - Factors Affecting Microelectronics

Higher functional integration/density
System-on-a-chip
Modular system design
Advanced packaging techniques
Low and ultra-low power
Fault tolerant
Reconfigurable systems
Rapid prototyping/simulation
Scalable real-time multiprocessing
Operation at cold temperature
High-bandwidth communications and free space interconnects
Increased processing capability
On-board autonomy, data reduction
Increased reliability
Integrated power management and distribution
Radiation tolerance
Availability, cost, ...

While advanced and new technologies are exciting not only to the space system designers, but also to the technology evaluators such as ERC, support for the core needs of space system electronics designers must also be included. The typical spaceflight electrical designer is not concerned over the new emerging "Unobtanium razz-matazz" that they might be able to use in ten years, but with making sure that the current technology devices in their designs are reliable in the space radiation environment. Thus, it is incumbent upon the ERC project to support these core needs on current devices and technologies.

The following sections discuss what the ERC project is and how it supports this dichotomy of needs from core support to the future breakthrough technologies.

5. ERC Roadmap for Technology Evaluation

In order to align with NASA's technology development roadmaps, the ERC project divides it's technology evaluation, assessment, and characterization efforts into four broad categories. These are:

- Breakthrough bandwidth/speed microelectronics and photonics such as fiber data links,
- Breakthrough volumetric technologies such as MEMS,
- Harsh environment components and technologies such as extreme temperature electronics, and,
- Other enabling devices and technologies including power electronics, commercial microelectronics and photonics, and advanced sensors.

Figures 3-6 represent the roadmap of technologies that the ERC project seeks to evaluate and assess for radiation characteristics in each of the four categories. The selection of technology evaluation tasks is revisited on a yearly basis and is based on customer utility, technology readiness levels (TRLs), leverage with technology developers, partnering with other government agencies, industry, and academia, and funding availability. TRLs indicate the maturity of the technology. The ERC project emphasizes those technologies that have already demonstrated manufacturing feasibility or are commercially available.

Radiation technology evaluations are performed in conjunction with semiconductor manufacturing partners. The data that is gathered is used to generate models for technology sensitivity and allows for feedback to the manufacturer for radiation hardening solutions, guideline development for technology users, and as input to improved ground radiation test methods and space performance prediction models and tools.

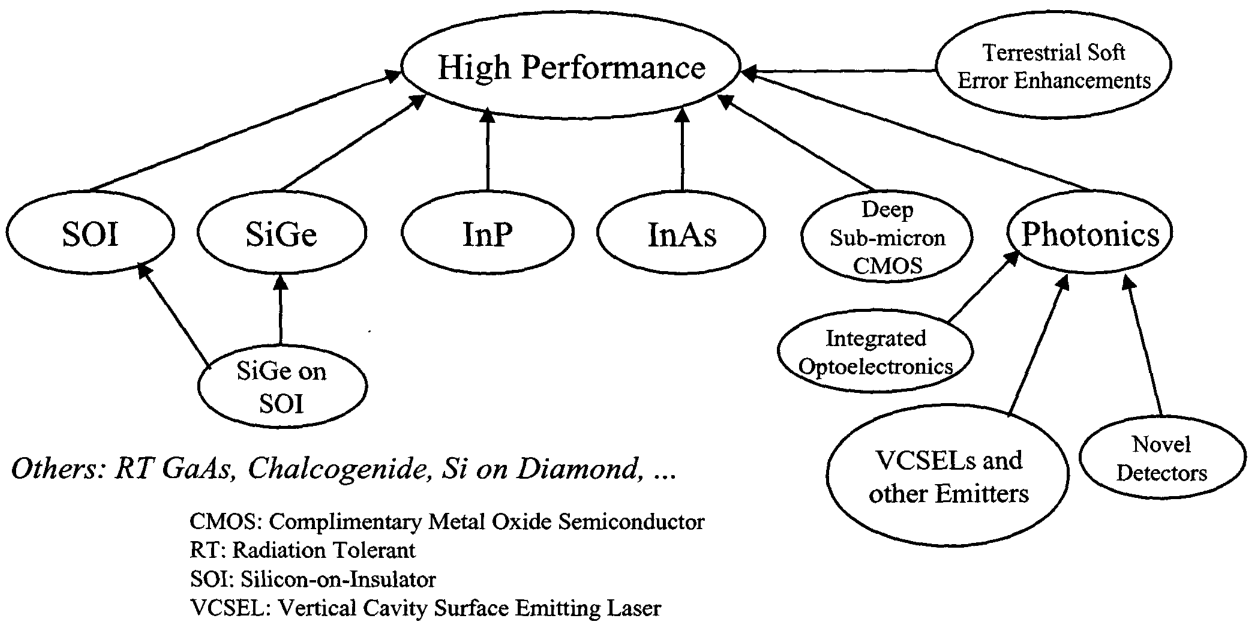
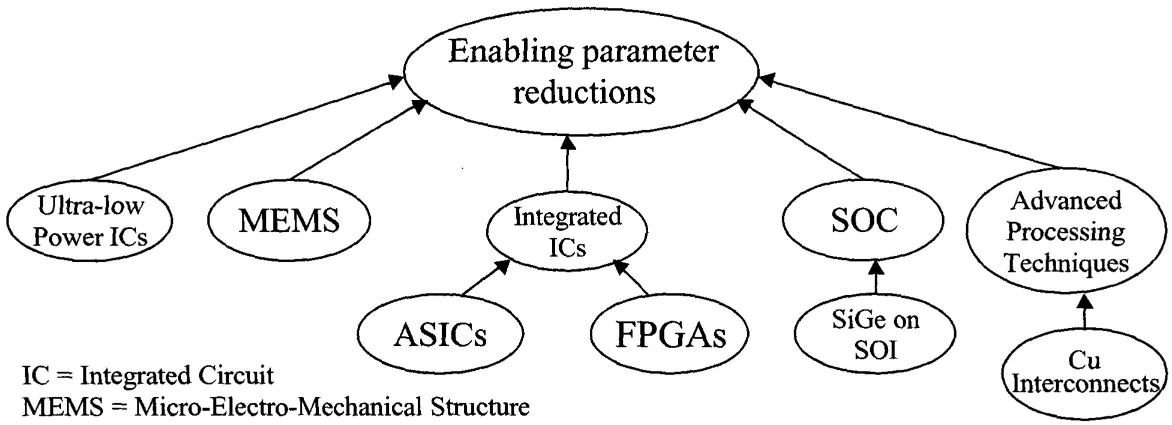
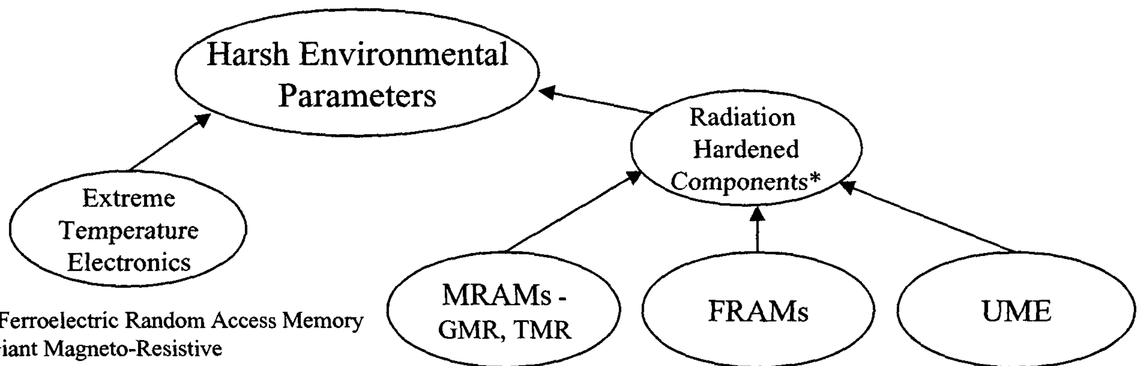


Figure 3 ERC Project Microelectronics Technologies Roadmap – Breakthrough Bandwidth/Speed



IC = Integrated Circuit
MEMS = Micro-Electro-Mechanical Structure
SOC = System-on-a-Chip: may include numerous technologies including mixed signals (analog/digital) on single substrate

Figure 4 ERC Project Microelectronics Technologies Roadmap – Breakthrough Volume



FRAM: Ferroelectric Random Access Memory
GMR: Giant Magneto-Resistive
MRAM: Magnetic Random Access Memory
TMR: Tunneling Magneto-Resistive Memory
UME: Universal Memory Element

* = *not previously noted elsewhere*

Figure 5 ERC Project Microelectronics Technologies Roadmap – Harsh Environment

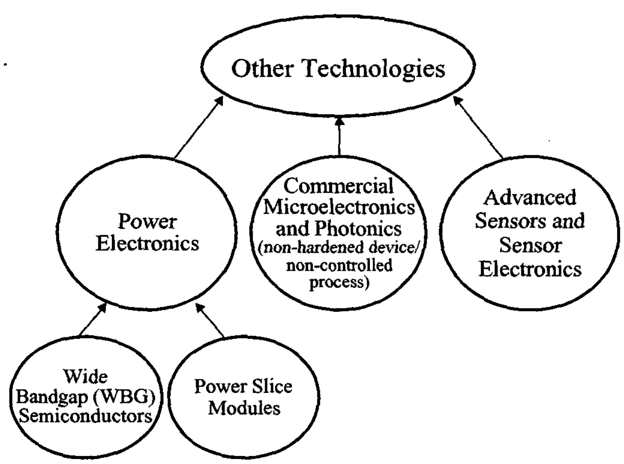
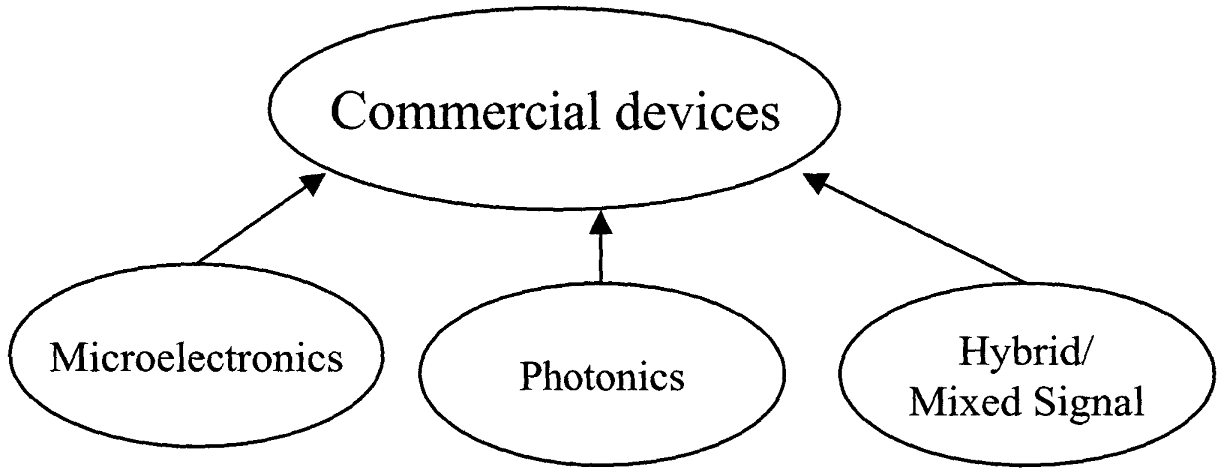


Figure 6 ERC Project Microelectronics Technologies Roadmap – "Other" Technologies

6. ERC ROADMAP FOR CORE FLIGHT CUSTOMER SUPPORT

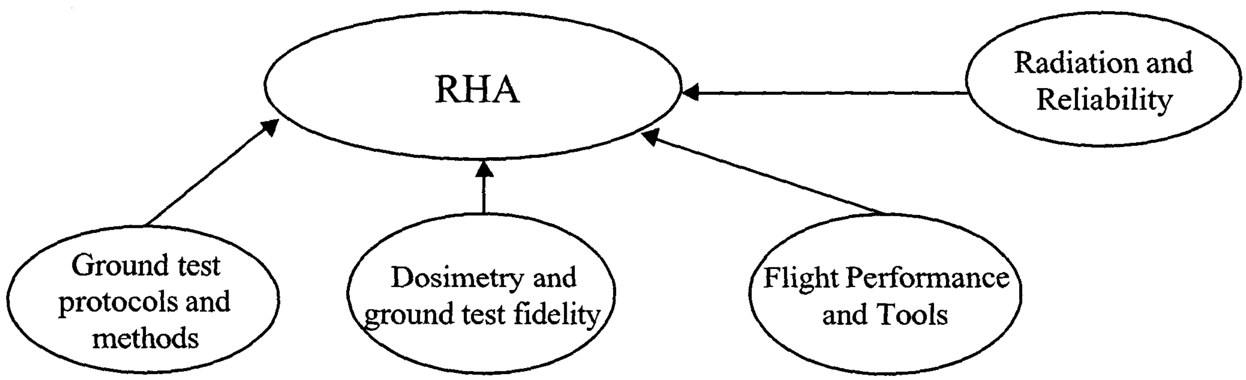
While the technology evaluation often seems to be the "sexy" part of the ERC project, the needs of today's space and avionic system designers must also be supported. In this regard, the ERC project's roadmap for core support may be divided into three general categories:

- Existing or state-of-the art (SOTA) commercial microelectronic and photonic device characterizations (this is aligned with ERC's technology evaluation roadmap as well),
- Investigation of "radiation-specific" issues on RHA such as test protocols, dosimetry, or radiation impact on reliability or in-flight performance, and
- Data dissemination to and education of the aerospace user community.



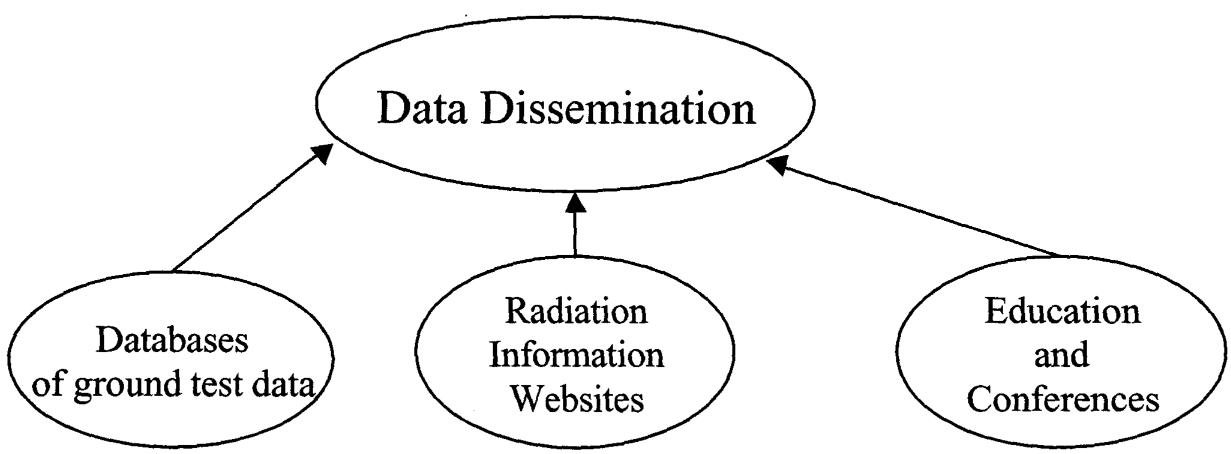
Output: Characterizations, Lessons Learned, Selection Guidelines

Figure 7 ERC Project Core Flight Customer Support Roadmap – Commercial Devices



Output: Improved FBC Test Methods, Improved Space System Reliability, Lessons Learned

Figure 8 ERC Project Core Flight Customer Support Roadmap – RHA



Data Dissemination is coordinated with the Information Management and Dissemination Project (IMDP) in the NEPP Program

Figure 9 ERC Project Core Flight Customer Support Roadmap – Data Dissemination

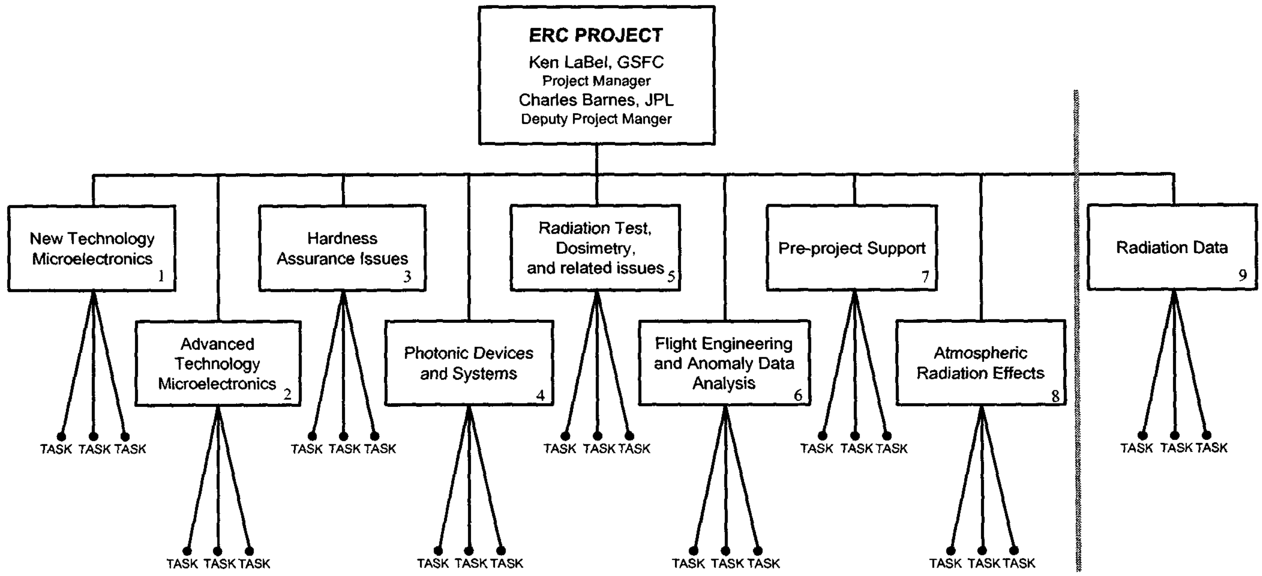


Figure 10 ERC FY00 Project Structure

Figures 7-9 illustrate the ERC project's roadmap for the types of efforts that fit within these categories. The selection of these tasks is again revisited on a yearly basis and is based on customer utility, leverage with flight projects, partnering with other government agencies, industry, and academia, and funding availability.

Tasks that fit into these are categories are focused heavily on providing utility to current NASA projects in or beginning development.

7. ERC STRUCTURE

As stated in the introduction, the ERC project's roles are to:

- provide radiation evaluations and assessments of new and emerging microelectronic and photonic technologies to enhance infusion into NASA missions,
- develop guidelines for technology usage in radiation environments, and
- investigate RHA issues in order to increase system reliability as well as to reduce system cost and delivery schedule [10].

The ERC project is a NASA-wide effort led by a Project Manager from GSFC and a Deputy Project manager from JPL and fosters task and customer participation from all NASA centers. Figure 10 illustrates the ERC project's organizational structure. The ERC project's efforts are divided into areas of emphasis that clearly map to the roadmap objective described in sections 5 and 6. These areas of emphasis are:

- Radiation characterization of **new microelectronics** devices including commercial products,
- Radiation evaluation of **advanced technology microelectronics**,
- Investigation of radiation **hardness assurance issues** that impact space and avionic designs (example: effect of single event latchup on device reliability),
- Radiation characterization and evaluation of **photonic devices and systems**,
- Investigation of **radiation test, dosimetry, and related issues** that impact space and avionic designs including test facilities and fidelity to the space environment,
- **Flight engineering and anomaly data analysis** for the performance of new and emerging technologies in a space radiation environment,
- Provide timely **pre-project support** for radiation risk assessments for small NASA projects and instruments,
- Evaluate the impact of **atmospheric radiation effects** on avionics and the commercial semiconductor industry (terrestrial impacts), and
- Maintenance and delivery of **radiation data** to the IMDP.

An additional area of emphasis will be included for FY01 in the area of **advanced sensor technology assessment.**

8. ERC COLLABORATION AND TEAMING

One familiar with the high costs of performing radiation evaluations such as non-recurring engineering (NRE), accelerator particle beam exposure, travel to energetic particle accelerators, as well as post-experiment data analysis, might saliently state that NASA is not capable of performing all of this critical work under its limited funding profile. This is a valid assessment. Proposal requests for funds far exceed the capability of the NEPP program. By prioritization of proposed yearly tasks in order to emphasize getting the most "bang for the buck" for the customers, the ERC project provides cost-efficient means of supporting key NASA interests. However, some significant areas on the ERC roadmap are under-funded. An increased funding profile would allow for improved customer support by providing a more complete coverage of ERC roadmap areas with an increase in the breadth of tasks supported and a decrease in the schedules of many planned tasks.

One of the prime means of extending the "effective" funds for ERC project efforts is by forming collaborations and teaming with other government agencies, industry, academia, and by utilizing existing and emerging consortia for radiation effects and RHA [10]. In particular, the ERC project plans are leveraged with many of the efforts funded by the Defense Threat Reduction Agency's (DTRA's) Radiation Tolerant Microelectronics (RTM) Program. Like the ERC project, the RTM provides support for radiation evaluation of emerging technologies and RHA issues. Other government collaborators and radiation team members include Air Force Research Laboratory (AFRL), Naval Research Laboratories (NRL), Naval Surface Warfare Center (NSWC) – Crane, Sandia National Laboratories (SNL), as well as foreign agencies such as European Space Agency (ESA) and the French space agency CNES. This leveraging is typically accomplished through in-kind or direct task funding by these agencies. In addition, collaborations extend the scope of information dissemination in the aerospace community.

As noted earlier, the ERC project is coordinated with other efforts leading to enabling systems in space such as the SEE program and NASA technology developers such as the CETDP. In addition, teaming or in-kind contributions takes place with original equipment manufacturers (OEMs) in the aerospace and semiconductor industries or with academia for the exploration of novel technologies of NASA's best interest or RHA issues. Coordination with academia is strongly encouraged. Plans for FY00 include collaborations with Auburn University, Clemson University, and Vanderbilt University.

Many of the ERC projects' efforts are supported by the semiconductor industry. A simple (and best) example is the provision of technology test samples by the device manufacturer for radiation characterization. Feedback from the ERC project aids these companies in producing flight-qualifiable components or gaining insights for radiation hardening solutions.

9. ERC Tasks – FY00 and Beyond

The 26 FY00 tasks were down-selected from over 100 task submissions based on an independent assessment of the proposals as well as a required coupling to the ERC project's goals. The funded tasks for FY00, their purpose, prime area of emphasis, main coupling to existing NASA roadmaps for technologies, and leveraged external organizations are shown in Table 2. GSFC and JPL are the accomplishing centers for FY00, but customer participation from all NASA centers is anticipated. In addition to these tasks, periodic customer reviews and educational meetings are held at various NASA centers.

At the time of this writing, the FY01 planning phase is occurring. With an expected increase in the ERC project's funding profile from FY00, an increase in the depth and breadth of the support for the ERC project's roadmaps is anticipated. Extension is expected in the areas of characterizations and evaluations of commercial devices, extreme temperature electronics, magnetic electronics, fiber optic technologies, and sensor technologies as well as the investigation of FBC test and qualification methods.

10. Summary

The ERC project is the research arm of NASA's plans for the evaluation and characterization of microelectronic and photonic technologies and the investigation of radiation-related issues.

The hazard that the ERC project faces is the space and terrestrial radiation environments. Issues with microelectronics and photonics include TID, displacement damage, and SEE.

NASA needs for microelectronics and photonics often have divergent characteristics: enabling electrical or mechanical performance, but severe reliability constraints. Thus, the ERC project emphasizes both technology evaluation and radiation reliability investigation.

The ERC project's roadmaps have two perspectives: technology and customer support. Technology support includes characterization and evaluation of emerging and commercial technologies that support NASA's technology roadmaps. Core customer support roadmaps emphasize the characterization of commercial components, the investigation of RHA issues, and the providing of information to the customers.

The ERC project is a multi-center effort whose roadmaps are mirrored into task categories called areas of emphasis. Nine areas of emphasis exist for FY00 with a tenth planned for FY01.

The ERC project fosters teaming and collaborations to extend the scope of its work as well as to broaden the breadth of information dissemination. Strong partners in DoD and other government agencies, industry, foreign government agencies, and academia exist.

Table 2 ERC Project FY00 Tasks

Task Name	*Purpose*	*ERC Area of Emphasis*	*Main Coupling to NASA Roadmaps*	*Leveraging such as in-kind contributions*
Commercial Programmable Technologies Characterization	Evaluate the radiation hardness of commercial programmable technologies such as field programmable gate arrays (FPGAs).	New	Reconfigurable computing, FBC designs	Industry
Linear Transient Investigation	Investigate radiation-induced transients in linear devices to determine test and mitigation methods as well as in-flight prediction method.	New	Increased system reliability	Industry, DoD, ESA
Volatile and Non-Volatile Memory Device Evaluations	Evaluate the radiation hardness of commercial memory technologies.	New	Increased system performance and reduced volume	DoD, Industry R&D
Effects of Scaling and Low Power Technology	Investigate the effect of scaled feature size and reduced voltages on radiation tolerance of CMOS semiconductors.	New	Higher performance, reduced volume and power, radiation tolerance	DoD, DOE, Industry
Linear Damage Investigation	Investigate radiation-induced damage in linear devices to determine test and mitigation methods as well as in-flight prediction method.	New	Increased system reliability	DoD, DOE, Industry
Commercial ADC/DACs Characterization	Evaluate the radiation hardness of commercial ADCs/DACs.	New	Increased system reliability	Industry, ESA
Ferroelectric Device Evaluation	Provide radiation evaluation support for novel ferroelectric technology emerging for use in memory devices.	Advanced	Radiation tolerance, increased reliability	Industry, DoD
SiGe Technology Evaluation and Modelling	Provide radiation evaluation support and modelling to determine radiation hardening paths for novel SiGe technology emerging for use in radio frequency (RF), detector, and other space subsystems.	Advanced	Higher performance, reduced volume, radiation tolerance	DoD, Industry, OEMs
Study of FBC Qualification Methods	Determine feasibility of improving current test techniques or feasiblity of developing new test methods for qualification	Advanced	Radiation tolerance, increased reliability	Industry, DoD, DOE
Novel Isolation Device Investigation	Evaluate the radiation tolerance of isolation technologies.	Advanced	Radiation tolerance, increased reliability	Industry, DoD
Fiber Optic System In-flight Performance Tool	Provide analysis tool for determining radiation-induced bit error rates (BERs) and degradation of optical systems such as optocouplers and fiber links.	RHA	Reduces design margins	DoD
IC Reliability Post-SEL	Investigate the effects of single event latchup (SEL) on long-term reliability of semiconductor devices.	RHA	Increased system reliability	DoD, Industry
Commercial VCSEL-based Fiber Optic Link Support	Provide radiation evaluation support for novel photonic technologies being used to develop a radiation-tolerant fiber link.	Photonics	Higher performance, reduced volume, radiation tolerance	Department of Defense (DoD), Industry Research and Development (R&D)
MEMS Evaluation	Provide radiation evaluation support for novel MEMS structures.	Photonics	Higher performance, reduced volume, radiation tolerance	Department of Energy (DOE)
Optocoupler Damage Mechanisms	Investigate radiation damage mechanisms in optocoupler devices to determine test method and in-flight prediction method.	Photonics	Increased system reliability	DoD, DOE, Industry
Optocoupler Transient Mechanisms	Investigate radiation-induced transients in optocoupler devices to determine test and mitigation methods as well as in-flight prediction method.	Photonics	Increased system reliability	DoD, DOE, Industry
Advanced Photonic Detector Investigation	Evaluate the radiation tolerance of novel detectors for photonic links such as metal semiconductor metal (MSM) detectors.	Photonics	Higher performance, reduced volume and power, radiation tolerance	DoD, Industry R&D
Optical Fiber TID Survey	Evaluate the radiation hardness of optical fiber technologies.	Photonics	Higher performance, reduced volume and power, radiation tolerance	OEMs, Industry
Non-Ionizing Energy Loss (NIEL) for Compound Semiconductors	Determine the radiation degradation damage functions of novel compound semiconductor materials as a function of particle species and energy.	Test Issues	Reduces design margins	DoD, DOE
Microelectronics and Photonics Testbed (MPTB) DR1773 Flight Data Analysis	Evaluate the radiation-induced in-flight perfomance of a fiber link (AS1773).	Flight data	Higher performance, reduced volume and power, radiation tolerance	DoD, DOE, Industry R&D, Industry
Engineering Data Analyses of Flight Electronics	Evaluate the radiation-induced in-flight perfomance of commercial technologies.	Flight data	Higher performance, reduced volume and power, radiation tolerance	DoD, DOE, Industry R&D, Industry, CNES, NASA Projects
Extension of Project-Specific Tests	Extend radiation tests from project-specific test levels to generic levels applicable to a wider range of space missions.	Project	Increased system reliability	Industry
Sematech white paper	Provide support for a joint NASA and Sematech analysis of semiconductor roadmaps and radiation assurance.	Atmosphere	Increased system reliability	Industry
Neutron rate prediction/Alpha test method	Determine a proper radiation assurance prediction method for neutron-induced effects on avionic systems as well as support for Sematech alpha test method guidelines.	Atmosphere	Increased system reliability	Federal Aviation Administration (FAA), DOE, NASA Projects, Sematech, Industry
RADATA website maintenance and data entry	Provide maintenance and new data entry for existing RADATA website and database.	Data	Increased data dissemination	NASA Projects, IMDP
RADHOME website maintenance and data entry	Provide maintenance and new data entry for existing Radhome website and information center.	Data	Increased data dissemination	NASA Projects, IMDP

The FY00 plan has 26 tasks that map to the ERC project's areas of emphasis. Selection of tasks is based on ERC project goals, roadmaps, independent assessments, and customer advocacy. Plans for tasks beyond FY00 are expected to expand the horizon of the ERC project for further critical technology and RHA support.

11. ACKNOWLEDGEMENTS

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